Arnold Schwarzenegger
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THE ECONOMIC COST OF CLIMATE CHANGE IMPACT ON CALIFORNIA WATER: A SCENARIO ANALYSIS

PIER PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

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July 2006
CEC-500-2006-003

California Climate Change Center
Report Series Number 2006-005

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Contract No. 500-02-004
Work Authorization MR-006

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Please cite this report as follows:

Hanemann, M., L. Dale, S. Vicuña, D. Bickett, and C. Dyckman. 2006. *The Economic Cost of Climate Change Impact on California Water: A Scenario Analysis.* California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2006-003.

Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

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- Buildings End-Use Energy Efficiency
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The California Climate Change Center (CCCC) is sponsored by the PIER program and coordinated by its Energy-Related Environmental Research area. The Center is managed by the California Energy Commission, Scripps Institution of Oceanography at the University of California at San Diego, and the University of California at Berkeley. The Scripps Institution of Oceanography conducts and administers research on climate change detection, analysis, and modeling; and the University of California at Berkeley conducts and administers research on economic analyses and policy issues. The Center also supports the Global Climate Change Grant Program, which offers competitive solicitations for climate research.

The California Climate Change Center Report Series details ongoing Center-sponsored research. As interim project results, the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the Center seeks to inform the public and expand dissemination of climate change information; thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

The work described in this report was conducted under the Preliminary Economic Analyses of Climate Change Impacts and Adaptation, and GHG Mitigation contract, contract number 500-02-004, Work Authorization MR-006, by the University of California, Berkeley.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contact the Energy Commission at (916) 654-5164.

Table of Contents

Abstract

This project focused on the impacts on water supply in California and provides a rough estimate of the economic consequences of several of these impacts. The project targeted a specific emission scenario, a specific global climate model, and a specific time period—the A2 emission scenario modeled using the Geophysical Fluid Dynamics Laboratory (GFDL) global climate model. The report provides a partial analysis of the economic costs caused by the reduction in surface water supply in California due to the GFDLA2 scenario to agricultural water users in the Central Valley and urban users in the South Coast. Although the specific details of their water supply differ, it is likely that agricultural users in California *outside* the Central Valley and urban users *outside* the South Coast will suffer economic losses because of this climate change scenario. It is important to note that this project examined only *one* scenario of what climate change might bring to water users in California—it is not the *only* possible scenario. The report constructs an analytic framework that will form a basis for future work, and other scenarios will be considered in future studies.

Executive Summary

Introduction

Climate change is likely to have a significant effect on California's water supply because rising winter temperatures are expected to lead to a diminished accumulation of snow in the Sierra Nevada, which functions as a natural form of water storage for California. The Sierra snowpack, which provides storage equal to about half the storage capacity in California's major human-made reservoirs, is released as the snow melts in the spring and early summer. Higher winter temperatures mean that more precipitation will fall as rain instead of snow, and the snow that does fall will melt earlier in the spring.

Purpose

This project's purpose was to focus on climate change impacts on water supply in California and to provide a rough estimate of the economic consequences of several of these impacts.

Project Objectives

The project focused on the A2 emission scenario, modeled using the Geophysical Fluid Dynamics Laboratory (GFDL) global climate model, with the objective of constructing an analytic framework that forms a basis for future work.

Project Outcomes

This report provides a partial analysis of the economic costs caused by the reduction in surface water supply in California due to the GFDLA2 scenario.

Conclusions

Agricultural water users in the Central Valley could experience a 8%–%14 drop in net revenues as the result of climate changes. Urban users in the South Coast could suffer a $1–$2 billion per year loss to consumer welfare.

After examining the economic impact on agricultural water users in the Central Valley and on urban users in the South Coast, the research team noted that it is likely that agricultural users in California *outside* the Central Valley and urban users *outside* the South Coast will suffer economic losses because of this climate change scenario, although the specific details of their water supply differ. It is possible that the economic impact on urban water users elsewhere in the state—especially the Bay Area and perhaps the Central Valley—may be roughly equal in total magnitude to that of urban users in the South Coast.

As noted earlier, the foregoing is only <u>one</u> scenario of what climate change might bring to water users in California, and future work will consider others.

Two qualifications should be emphasized. First, the more storage developed by water agencies in the South Coast, the greater the chance of reducing economic losses due to shortages in dry years. Second, an increase in water transfers from agricultural to urban users plays a crucial role in these analyses. For example, if all of the water currently used by agriculture in Imperial Valley were transferred to urban users in the South Coast region, this would roughly make up the entire increment in supply needed to meet urban growth in the region between 2006 and 2085. Whether or not that is a plausible scenario without climate change is not known. Also unknown is the potential effect of climate change on the total supply of water to California from the Colorado River. Even with more extensive water transfers from agricultural to urban users, it seems likely that climate change could create some shortages and impose some costs.

Recommendations

Future research should conduct sensitivity analyses of the assumptions used in this report and examine other emission scenarios, other global climate models, and other parts of the century.

Benefits to California

This work provides researchers and California decision makers with an analytical framework to use when examining the economic costs of climate change on California's water supply. As a changing climate alters California's water supply, such economic analyses will be beneficial for supporting the state's water supply decisions.

1.0 Introduction

The report by Cayan et al. (2005) presents several scenarios of future climate change in California and traces out the resulting impacts on agriculture, forestry, water, fire, coastal resources, and public health over the course of this century. This report focuses on the impacts on water supply in California and attempts to provide a rough estimate of the economic consequences of several of these impacts. The focus is on a specific emission scenario and a specific global climate model—the A2 emission scenario modeled using the Geophysical Fluid Dynamics Laboratory (GFDL) global climate model. The economic analysis focuses specifically on the consequences of climate change resulting from this emission scenario. Future work will fill out this picture, conducting sensitivity analyses of the assumptions used here and examining other emission scenarios, other global climate models, and other parts of the century. However, this report constructs an analytic framework which will form a basis for this future work.

The report is organized as follows: Section 2 provides a review of the hydrologic consequences of the emission scenario and global climate model selected for analysis; Section 3 examines the economic impact on agricultural water users in the Central Valley; and Section 4 considers the economic impact on urban water users in Southern California. Section 5 touches briefly on floods. Section 6 offers a few concluding observations and qualifications.

2.0 A Climate Change Scenario

The analysis that follows is based on the A2 scenario for global emissions (a medium-high emissions scenario), as analyzed via the GFDL global climate model (a medium-sensitivity climate model), and then downscaled to California and translated into surface hydrology in California via the variability infiltration capacity (VIC) model; further details of this scenario are provided in Cayan et al. (2005).

An important feature of the climate model results is that temperatures increase as the century progresses, with warming in winter and even greater warming in summer. Over the period 2035–2064, the average temperature in December–February in Northern California increases by 1.7°C (3.1°F), while the average temperature in June–August increases by 3.4°C (6.1°F); over the period 2070–2099, the average increase in winter temperature in Northern California is 3.4°C (6.1°F), while that in summer temperature is 6.4°C (11.5°F). In contrast to the change in temperature, there is expected to be relatively little change in precipitation in California.[1]

However, the climate change is still likely to have a significant effect on California's water supply because the rising winter temperatures are expected to lead to a diminished accumulation of snow in the Sierra Nevada, which functions as a natural form of water storage for California. While about 80% of our precipitation falls in the winter between October and March, about 75% of all water use in California occurs in the late spring and summer, between April and September. California relies on

[1] More generally, an analysis of 11 global climate models by Maurer (2005) finds only modest changes in annual precipitation in California, with some increase in winter months but a decrease in spring months.

reservoirs to store the winter precipitation for warm-season use, and also relies on the Sierra snowpack, which provides a natural storage equal to about half the storage capacity in California's major human-made reservoirs. Water stored in the snow pack is released as the snow melts in the spring and early summer. The higher winter temperatures mean that more precipitation will fall as rain instead of snow, and the snow that does fall will melt earlier in the spring. The projected change in snow water equivalent (SWE) in storage in the snowpack on April 1 in the Sacramento, San Joaquin, and Trinity drainages (as a percentage of the historical average for 1961–1990) amounts to an average loss of 37% over the period 2035–2064, and 79% over the period 2070–2099 (Cayan et al. 2005).

The increase in precipitation falling as rain rather than snow has two implications with potential economic consequences. The shift from snow to rain implies an increase in direct winter runoff, which has the potential to cause flooding damage downstream in the watershed. And, with more of the annual runoff occurring earlier in the year at a time when reservoir space is needed for flood control, some runoff that was used historically for water supply may now be lost unless some form of additional storage is developed.

There is clear evidence that these trends are already under way. Since about 1950 snow accumulation has already shown losses on the order of 10% in April 1 snow water equivalent across the western coterminous United States (Mote et al. 2005). Over this period, the onset of the snowmelt spring pulse has shifted forward in time by 10–30 days throughout the western United States, with the largest shifts seen in the Pacific Northwest and the Sierra Nevada (Stewart et al. 2005). In California, the 100-year, 3-day peak flows on the American, Tuolumne, and Eel Rivers has more than doubled between the first half of the twentieth century and the second; more generally, the annual peak 3-day mean discharges are becoming more variable and larger for most sites in California (Chung et al. 2005).

The available climate model data are on a monthly timescale which does not lend itself well to a detailed simulation of changes in peak flow runoff, which typically are associated with individual storm events occurring over the span of a few days. However, Chung et al. (2005) provides an illustration of the potential for increased winter flooding using a simple hydrologic model of the Feather River watershed and simulating the peak runoff in a winter storm as the snow level elevation rises from 4,500 feet (1,400 meters, m) to successively higher levels with increasing winter temperature. As the snow-level elevation rises to 5,000, 6,000, or 7,000 feet (1,500, 1,800, 2,100 m), the peak runoff from a winter storm increases by 23%, 83%, and 131%, respectively; with each increase, there is a higher probability of flooding in the Sacramento Valley.

In addition to the change in the timing of streamflow into the major reservoirs of the Sacramento Valley, modeling shows some change in the overall volume of inflow, although the change is small at first. In the period 2035–2064, the median inflow (i.e., the inflow that occurs at least 50% of the time) at Shasta and Oroville is virtually the same as in the historical past (1922–1974), but there is now a smaller probability of large inflows;

an inflow that occurred about 25% of the time historically might now occur only about 15% of the time (Joyce et al. 2005).[2] In 2070–2099, however, the median inflow at Shasta is about 15% lower than the historical record, about 25% lower at Oroville, and about 33% lower at Folsom.

The description that follows is drawn from Chung et al. (2005) and Vicuna (2005), and is based on the use of CalSim II to simulate the changed streamflow hydrology. CalSim requires as input a given time series of monthly stream flows—it uses a modified version of the historical stream flow over the period 1922–1994. Climate change is incorporated into the given historical series by the "perturbation ratio" method. For a given time period of interest (2035–2064, or 2070–2099), a given stream location, and a particular month, one computes the average ratio of the streamflow in that month over the period of interest to the streamflow for the corresponding month over a base period (1961–1990); the monthly ratios are then used to adjust, or "perturb," the monthly stream flows in the historical series 1922–1994. While convenient, the perturbation ratio approach ties the simulation of the climate change scenario to the historic pattern of variation in drought and wetness.

A way to characterize the change in inflow is by reference to the Sacramento Four River Index, which is used to classify the type of water year into five categories: wet, above normal, below normal, dry, and critical.[3] Over the historical period 1922–1974, 48% of the years were wet or above normal, and 40% were dry or critical. With the climate change scenario, there is a small shift in this distribution by 2035–2064: 46% of the years are wet or above normal, while 47% are dry or critical. By 2070–2099, however, only 22% of the years are wet or above normal, while 70% are dry or critical Vicuña (2005). As explained below, the increase in incidence of dry or critical years would also be accompanied by longer and more severe drought spells.

The reduction in overall inflow to major reservoirs and the change in the timing of inflow translate into reduced deliveries to water users both in the Sacramento Valley by the Central Valley Project (CVP) and in the San Joaquin Valley by CVP and state water project (SWP). In 2035–2064, the median delivery (i.e., the quantity that is delivered at least 50% of the time) to SWP contractors south of the Delta falls by 11% (compared to the median historical delivery over 1922–1974), while the median delivery to CVP contractors south of the Delta falls by 14.5% (Chung et al. 2005).[4] In 2070–2099, the median delivery to SWP contractors south of the Delta falls by 27.3% (compared to the

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[2] In the case of Folsom, the median annual inflow falls by about 12%.

[3] The index is a weighted average of April–July unimpaired runoff (40%), October–March unimpaired runoff (30%), and the previous year's index (30%). Unimpaired runoff is calculated as the sum of Sacramento River flow, Feather River flow, Yuba River flow, and American River flow. A water year with an index equal to or greater than 9.2 million acre-feet (MAF) is classified as *wet;* a year with an index equal to or less than 5.4 MAF is classified as *critical.*

[4] In both cases, the quantity of water that corresponds to the historical median delivery is now delivered only about 28% of the time.

median historical delivery), while the median delivery to CVP contractors south of the Delta falls by 31.4% (Vicuña 2005).[5] The reduction in deliveries is likely to be distributed unevenly among contractors, depending on prior surface water rights (exchange contractors), water contract commitments, and type of use, with urban users favored over agricultural users in a severe shortage.

In the 1987–1992 drought, for example, the CVP and SWP were able to meet delivery requests during the first four years of the drought, but were then forced by declining reservoir storage to cut deliveries substantially in 1991. The CVP cut agricultural deliveries by 75% and urban deliveries by 25% in 1991 while, with its smaller storage capacity, the SWP cut urban deliveries by 70% and provided no agricultural deliveries.

The analysis of the reduction in surface water deliveries under the climate change scenario for alternative CVP and SWP contractors is presented in the next section, and focuses on economic impacts over the period 2070–2099.

Before concluding this section, one caveat should be noted. It was mentioned above that the CalSim analysis uses the perturbation ratio method to simulate the consequences of the change in streamflow hydrology. This assumes implicitly that the future hydrology with climate change will look broadly like the historic hydrology. That may be incorrect, and it could understate the degree of uncertainty likely to be faced in the climate change scenario. An alternative approach uses the Water Evaluation and Planning (WEAP) model (Joyce et al. 2005), which processes the raw time series of precipitation and temperature through a watershed hydrology model and directly generates a time series of stream flows. This provides more latitude for a change in hydrology. The WEAP simulation applied to the climate change scenario suggests the possibility of a more prolonged drought at the end of the century than the CalSim simulation, lasting up to 15 years. However, the WEAP hydrology only covers the Sacramento Valley at this time, and therefore the WEAP simulation is not analyzed further because it does not account for economic losses in the San Joaquin Valley.

3.0 Economic Impact on Central Valley Agriculture

In 2000, which is considered a normal water year, agriculture in the Central Valley used about 26 million acre-feet (MAF) of water, of which 65% came from surface water and the remainder from ground water (DWR Bulletin 160-05, forthcoming). About 6.5 MAF (38%) of the surface water was supplied by the CVP and SWP; the remainder came through diverters exercising their own rights to surface water. In 2070–2099, climate change under the GFDLA2 scenario is expected to significantly reduce the amount of surface water available to Central Valley agriculture, including irrigation districts served by the CVP and SWP and other agricultural water users with their own rights to surface water. For the purpose of this analysis, we assume that essentially the same acreage of

[5] In the SWP case, the quantity of water that corresponds to the historical median delivery is now delivered only about 26% of the time; in the CVP case, however, the delivery level that corresponds to the historical median is never attained now. North of the Delta, there is only a small reduction in CVP deliveries; the median delivery falls by 2%.

land in the Central Valley is potentially farmed and apply an economic model of near-term farming conditions to simulate the economic impact of the change in surface water availability if it were superimposed on the near-term farm economy.[6]

The change in surface water availability varies across year types and is summarized in Table 1 for the Sacramento Valley and for the San Joaquin Valley, broken down into two sub-regions: the San Joaquin Basin and the Tulare Lake Basin. In the Sacramento Valley over the period 2070–2099, modeling shows almost no change in the amount of surface water available to agricultural users about 50% of the time; in the worst 15% of the years, there is a reduction which amounts on average to 53%. In the San Joaquin Valley combined, half the time there is a reduction in surface water availability which averages about 10%; in the next 35% of years, the reduction averages 48%; and in the worst 15% of years it averages 68%. Over all years combined, the average reduction in surface water availability amounts to 12% in the Sacramento Valley and 32% in the San Joaquin Valley.

TABLE 1. CHANGE IN SURFACE WATER AVAILABLE TO AGRICULTURAL WATER USERS IN THE CENTRAL VALLEY, 2070-2099

	REGION		
	Sacramento Valley	**San Joaquin Basin**	**Tulare Lake Basin**
APPLIED WATER USE IN 2000 (TAF)	7,735	7,358	10,879
% Surface water	64%	74%	60%
% Groundwater	36%	26%	40%
CHANGE IN SURFACE WATER AVAILABILITY 2070-2099 (Surface water with climate change/surface water used in 2000)			
YEAR CATEGORY			
Upper 50% of years	98%	91%	90%
Next 35% of years	90%	52%	51%
Lowest 15% of years	47%	33%	30%
Average of all years	88%	69%	67%

Farmers are likely to respond to the reduction in surface water availability by changing crops, changing irrigation methods, changing their source of water to groundwater, and

[6] It is likely that the irrigated acreage in the Central Valley will shrink somewhat over time, due to fallowing associated with transfers of water to urban areas along the Coast and in the Central Valley. To the degree that fallowing draws lower value crop land out of production, the economic impacts presented below will be underestimated. That is because additional fallowing associated with climate change is likely to be from the higher value cropland that remains in production after transfers. It should be noted that the analysis assumes a 2020 level of development.

in some cases by fallowing land.[7] The present analysis accounts for these changes on the basis of an annual assessment of market equilibrium for Central Valley agriculture based on the maximization of producers' surplus plus consumers' surplus.[8] In this analysis, groundwater plays an important role because in most parts of the Central Valley farmers can pump groundwater to replace surface water if they choose. However, this will cause groundwater levels to fall over time, which in turn increases the cost of pumping groundwater. In many cases, the chief effect of climate change becomes an increased cost of groundwater rather than the reduced quantity of surface water per se.[9] The change in groundwater depth was calculated through the use of C2VSIM, the California Department of Water Resources' (DWR's) integrated groundwater and surface water model for the Central Valley which is still in the process of being calibrated.[10]

The impacts on Central Valley agriculture are shown in Table 2, where two sets of analyses are presented. One analysis is for an average year over the whole period 2070–2099; the other is for an average year among the lowest 15% of years when surface water availability is most heavily restricted. A different economic assumption is used in each case. In the average case analysis, it is assumed that farmers can respond to variation in water availability by changing crops or irrigation technology as well as water source. By contrast, the lowest 15% case is considered akin to a short-run drought emergency situation in which farmers have a given irrigation technology that cannot be modified in the short-run, so their only options are to pump more groundwater or modify their cropping pattern. In these circumstances, farmers are likely to give up their relatively less profitable crops and husband limited or expensive water for their more valuable crops (which are most likely to be tree crops).

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[7] Some of the land fallowing may be associated with the lease or sale of water to other water users. The analysis conducted here accounts for water sales to other agricultural users within the same local region, but not to agricultural users outside the local region, nor to urban users. This assumption will be relaxed in future work.

[8] We employ DWR's Central Valley Production Model (CVPM) which is a positive mathematical programming model of Central Valley agriculture calibrated to a 2020 level of development.

[9] This was what happened during the 1991–1992 drought: agricultural users mainly replaced reduced surface water with increased pumping of groundwater, while also giving up their less profitable field crops.

[10] See http://modeling.water.ca.gov/hydro/model/iwfm/documentation.html.

TABLE 2. ECONOMIC IMPACT ON CENTRAL VALLEY AGRICULTURE, 2070-2099.

	REGION			
	Sacramento Valley	San Joaquin Basin	Tulare Lake Basin	TOTAL
		AVERAGE OF ALL YEARS		
BASE CASE (No climate change)				
Acres in production ('000)	2,020	2,558	2,009	6,587
Gross revenue ('000 $ 2004)	$2,174,195	$5,275,082	$4,630,040	$12,079,317
Net revenue ('000 $ 2004)	$429,246	$1,351,433	$1,315,157	$3,095,836
CLIMATE CHANGE CASE				
Acres in production ('000)	1,933	2,445	1,955	6,333
Gross revenue ('000 $ 2004)	$2,120,104	$5,152,107	$4,570,323	$11,842,534
Net revenue ('000 $ 2004)	$367,836	$1,241,453	$1,208,023	$2,817,312
DIFFERENCE DUE TO CLIMATE CHANGE				
Acres in production ('000)	-87	-113	-54	-254
Percent change	-4.3%	-4.4%	-2.7%	-3.9%
Gross revenue ('000 $ 2004)	-$54,091	-$122,975	-$59,717	-$236,783
Percent change	-2.5%	-2.3%	-1.3%	-2.0%
Net revenue ('000 $ 2004)	-$61,410	-$109,980	-$107,134	-$278,524
Percent change	-14.3%	-8.1%	-8.1%	-9.0%
		LOWEST 15% OF YEARS		
BASE CASE (No climate change)				
Acres in production ('000)	1,945	2,523	1,972	6,440
Gross revenue ('000 $ 2004)	$2,130,043	$5,249,450	$4,591,334	$11,970,827
Net revenue ('000 $ 2004)	$414,809	$1,339,591	$1,286,744	$3,041,144
CLIMATE CHANGE CASE				
Acres in production ('000)	1,408	1,765	1,392	4,565
Gross revenue ('000 $ 2004)	$1,769,657	$3,915,618	$3,522,524	$9,207,799
Net revenue ('000 $ 2004)	$286,060	$947,157	$1,004,780	$2,237,997
DIFFERENCE DUE TO CLIMATE CHANGE				
Acres in production ('000)	-537	-758	-580	-1,875
Percent change	-27.6%	-30.0%	-29.4%	-29.1%
Gross revenue ('000 $ 2004)	-$360,386	-$1,333,832	-$1,068,810	-$2,763,028
Percent change	-16.9%	-25.4%	-23.3%	-23.1%
Net revenue ('000 $ 2004)	-$128,749	-$392,434	-$281,964	-$803,147
Percent change	-31.0%	-29.3%	-21.9%	-26.4%

The analysis shows that, in an average year over 2070–2099, the climate change scenario leads to the fallowing of about 254,000 acres in the Central Valley, about 3.9% of the base irrigated acreage. It leads to a reduction in agricultural production with a gross annual value of $237 million, or 2% of the base gross revenue. In terms of net revenue (profit) from farming, the climate change scenario leads to an annual loss of $278.5 million, or 9% of the base net revenue. The loss of net revenue consists of two elements: there is a loss of net revenue on land that is now fallowed, and there is also a loss of net revenue on land that is still farmed, but with more expensive groundwater.

In the lowest 15% of years, the situation is more complicated. Because these are relatively water-short years, even without the climate change scenario some land is fallowed in these years and some revenue is lost. In the Central Valley as a whole, without climate change 147,000 fewer acres are farmed (2.2%) in the most critical years compared to the average year. With climate change, an additional 1.875 million acres is fallowed in the most critical years compared to the average year with climate change—a reduction of 29.1%. The reduction in the gross value of annual agricultural production amounts to $2.76 billion—a reduction of 23.1% compared to the average year with climate change, and 23.8% compared to the average year without climate change. The reduction in annual net revenue from Central Valley agriculture amounts to $803 million—a reduction of 26.4% compared to the average year with climate change, and 27.7% compared to the average year without climate change.

In addition to these economic impacts, two additional factors should be noted. First, because of the increased cost of groundwater pumping, the climate change scenario is associated with a higher cost of producing agricultural commodities in the Central Valley and this, in turn, affects commodity prices and creates a loss of economic welfare for the consumers and users of these commodities.[11] However, most of the consumers are likely to be out of state, so that relatively little of this economic impact is likely to be felt in-state. Secondly, the reduction in agricultural production in the Central Valley leads to some ripple effects on production and employment in the rest of the California economy. These effects are measured through the use of an input-output multiplier for the indirect and induced impact on statewide production associated with a direct change in production in a given sector. For Central Valley agriculture, the output multiplier is about 2.1 (Illingworth et al. 2005). Hence, in the lowest 15% of years, the reduction in Central Valley agricultural production (gross revenue) due to the climate change scenario translates into an economy-wide loss in annual State Gross Product amounting to about $5.8 billion.[12]

4.0 Economic Impact on Urban Users in Southern California

This section focuses on urban water use in the South Coast Hydrologic Region. This region includes the service area of the Metropolitan Water District of Southern California (MWD), which is the wholesale supplier to 26 cities and water districts, plus the service areas of a number of other water districts to the north and east of the MWD service area. The total population of the region in 2000 amounted to 18,223,425, of whom 16,843,200 lived within the MWD service area. Total urban water use in 2000 amounted

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[11] This loss will be quantified in a future analysis.

[12] The spillover effects from a reduction in agricultural production in the Central Valley to the rest of the California are especially likely to be felt in the context of short-term production disruption, such as that associated with the 15% case. The spillover effect would likely be smaller for a long-term shift in agricultural production, since there would be more time for economic substitution to occur.

to 4.2 MAF, of which 3.6 MAF was urban use within the MWD service area (DWR Bulletin 160-05; MWD 2005). The region's supply in 2000 included surface water from the SWP (about 1.3 MAF), surface water imported from the Colorado River (about 1.3 MAF), surface water imported from the eastern Sierra via the Los Angeles Aqueduct (LAA) (about 0.3 MAF), as well as local surface water and groundwater. The hydrologic analysis described in Section 2 accounts only for the effect of the GFDLA2 climate change scenario on deliveries from the SWP and deliveries from the LAA—i.e., about 38% of the region's total supply. It is likely that climate change will also affect the availability of surface water from the other sources, but as yet no information is available on this. Hence, our analysis proceeds as though the other 62% of the region's water supply would be unaffected by climate change. The incomplete accounting for climate change impact on surface water supply is an important point of difference between this analysis and that of Central Valley agriculture in Section 3.

Another important difference is the time frame for the analysis. In the case of Central Valley agriculture, this study analyzed the impact of future climate change as though it were superimposed on today's agricultural economy in that region. While this is clearly an unrealistic assumption, we believe it is not entirely unreasonable; the same type of assumption has been adopted in other studies of the impact of climate change on U.S. agriculture including the National Assessment (2002). In the case of urban water use in the South Coast, however, it would not be acceptable to proceed as though future climate change were superimposed on today's urban water economy, because of the rapid pace of population growth in the region. The population in the MWD service area is growing at a rate of about 300,000 people per year. The total population in the South Coast region is projected by DWR to grow by 31% between 2000 and 2030, from 18.2 to 23.8 million. Extrapolating from this rate of growth, we project that the population in the region may reach 27.5 million by 2050, and 34.1 million by 2085, the midpoint of the 2070–2099 period. The economic consequences of a climate-induced change in water supply for a population of 34.1 million versus 18.2 million are sufficiently different that the change in climate cannot be assessed in isolation from the change in population. Consequently, the economic analysis must be situated in an explicit scenario of future urban water demand and supply in the South Coast. This analysis focuses on 2085 as the midpoint of the 2070–2099 period, projects total urban demand and supply at that date, and then applies the climate change scenario for the 30-year period to those particular conditions.

When expressed on a per capita basis, total urban water use in the South Coast in 2000 amounted to an average of 208 gallons per capita per day (gpcd). We expect this per capita figure to fall over time because of increased efforts at conservation and technological change, as well as in response to an increasing real cost of urban water supply over time. There are two countervailing trends, however. First, much of the new urban development is likely to take place in interior areas away from the coast. All else being equal, these developments are likely to be associated with higher outdoor water use. Second, while new residential housing has more water efficient toilets and showerheads than the existing housing, there is a tendency for new homes to have more water-using fixtures and appliances per dwelling.[13] Given these considerations, we make the assumption that total urban per capita water use in the South Coast will fall from 208 to 178 gpcd by 2085.[14,15] Given the projected population, the total urban water use will amount to 6.8 MAF in 2085. This figure is intended to represent demand in a normal year; in a wet or a dry year, the actual demand would be different because of the reduction or increase in the demand for outdoor watering.[16]

The implication of these calculations is that the climate change scenario for 2070–2099 would be superimposed on an urban water system in the South Coast that, by 2085, will have to supply about 62% more water than it supplied in 2000.

How an urban area with over 30 separate retail water supply agencies will manage its water supply in the face of population growth and climate change 80 years hence is not something that can be assessed with any degree of certainty. The outcome will depend on decisions by individuals and agencies, both water users and water suppliers, on the evolution of the regional economy, and on technological developments that cannot be forecast now. The approach adopted here is to present a possible scenario of how these changes will work themselves out. This is only one of many possible scenarios; it is intended as a sketch of what might happen, not a prediction of what necessarily will happen. Future research will consider alternative scenarios, and will seek to engage a broad spectrum of interested parties in a conversation regarding the additional scenarios to be analyzed.

We assume here that the extra supply needed by 2085 will be obtained by various means, including water transfers from other areas in-state and out-of-state, new water supply technologies (e.g., wastewater recycling, desalination) and perhaps additional conservation beyond that already factored into our assumption of a 30 gpcd (14.4%) reduction in urban use by 2085. The present analysis does not specify how the additional 2.6 MAF supply is obtained, except for one important factor: it matters greatly whether the additional supplies are themselves likely to be affected by the climate change scenario. The key here is whether the new supplies involve surface water that would be affected by warmer winter temperatures, a shift from precipitation in the

[13] Moreover, even with a fixed number of residents per dwelling, if there are more toilets per dwelling, this can lead to more leakage and an increase in per capita water use.

[14] This figure assumes that, by 2085, average residential use falls to 120 gpcd throughout the South Coast region, industrial and commercial use combined fall to 42 gpcd, and what DWR Bulletin 160-05 calls "public use" falls to 9.5 gpcd while, as in 2000, "other" (including conveyance loss and groundwater recharge) amounts to 3.7% of total urban use.

[15] It certainly would be physically possible to reduce urban water use significantly below this level; see, for example, Gleick et al. (2003). The relevant question is whether and when water users and water agencies in California will be motivated to change their behavior to achieve such lower levels of water use, whether by economic or regulatory incentives.

[16] MWD (2005) indicates that per capita urban demand is about 8.33% higher in a dry year than a normal year; this would raise the potential urban demand in 2085 to 7.375 MAF.

form of snow to rain, and the shrinking of snow packs. If the new supplies were immune to climate change—for example, they came entirely from recycling or desalination—then only the 1.6 MAF from the SWP and LAA, out of the total supply of 6.8 MAF, would be liable to being reduced in the climate change scenario. Conversely, if *all* of the new supplies were from mountain systems in California, Oregon, Washington, or the Colorado River Basin that can be expected to be influenced by global warming, then 4.2 MAF (= 1.6 + 2.6) out of a total supply of 6.8 MAF would be liable to being reduced with climate change. For this analysis, we make the crude assumption that at least half of the new supplies involve surface water whose availability is likely to be affected by climate change.[17] We assume further that this new surface water supply is affected by climate change in the same manner as the existing SWP and LAA supplies.

Given these assumptions, climate change in 2070–2099 has two distinct consequences for urban water users in the South Coast. First, because of the reduction in surface water availability, climate change causes a reduction in the area's average supply, which needs to be made up by acquiring a new supply from some additional source. Second, climate change increases the frequency of droughts and exacerbates their duration and severity. These have different economic implications.

The economic consequence of the first change is to raise the cost of water supply for all users every year, because the expenditure on a replacement for the loss in average supply contributes to the water district's "baseload" supply.

The economic consequence of the second change is more complex, and reflects a fundamental difference in the operation of urban versus agricultural water supply agencies. Many agricultural suppliers have little storage, especially those served by the CVP and SWP who rely primarily on those projects' storage to provide some insurance against variability in supply. Another form of insurance is to arrange for additional supplies as a precaution through water market transactions, especially "dry-year" leases which provide water to the purchaser in drought years. Here, too, few agricultural water agencies purchase this "insurance." Instead, in a year when their own supplies are cut back due to drought, they reduce deliveries to agricultural users who are left to fend for themselves, either by short-term pumping of groundwater or by fallowing land. By contrast, urban water agencies are extremely reluctant to ration their water users, and they have invested heavily both in water market purchases and in developing storage either within-district or, more generally, south of the Delta. This is especially true of MWD which has been a pioneer of both strategies. The insurance means that urban users have to pay for some extra quantum of "baseload" supply beyond that needed to make average year supply match expected average year demand, but it also permits the water district to weather small supply shortfalls with no loss of well-being for urban water users. The need for rationing, and the concomitant loss of well-being for water users, arises only when the shortage exceeds some threshold level chosen by the water agency. This analysis sets the threshold at 5%: it assumes that baseload supply is made

[17] This is loosely consistent with the statement in MWD's 2000 Regional Urban Water Management Plan that a mix of local and imported water is the preferred alternative for new water supplies.

adequate to cover a 5% shortage compared to normal demand, and that shortage costs occur for water users only when the shortfall exceeds that threshold.[18, 19]

The resulting impact of the climate change scenario on the South Coast's urban water supply is shown in Tables 3 and 4. Table 3 summarizes the overall water supply situation, focusing on the average water supply over the period 2070–2099, while Table 4 focuses on the driest 35% of the years. Assuming that, of the region's existing supplies, only those from the SWP and LAA are affected, climate change reduces the region's present supply, on average, by 298,000 acre-feet, which amounts to a reduction of 19% in the SWP and LAA supply, and a reduction of 7% in overall supply. Population growth between 2000 and 2085 requires the region to acquire an additional 2.6 MAF in new supplies; allowing for a 5% margin of safety, raises this total to 2.73 MAF. To deal with the combined effect of population growth by 2085 and climate change in 2070–2099, the region would need a total of 3.03 MAF in new supplies. As indicated above, we assume that half of the new supplies come from surface water sources that would be affected by climate change in a manner similar to the existing SWP and LAA supplies, while the rest of the new supply comes from sources that are not affected by climate change.[20]

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[18] The analysis abstracts from the fact that in hotter years, which are also likely to be the water shortage years, urban demand is typically higher than in a normal year by a factor that was quantified by MWD at 8.33% (see note 16). The actual demand at a time of rationing is likely to be still higher for two reasons. First, the 8.33% is the increase in average *annual* demand in a dry year versus a normal year; but the actual increase is associated mainly with outdoor lawn watering during the *summer* months, which is when the shortfall occurs. In those months, the degree of shortfall is larger. Furthermore, with more of urban population living in hotter, interior areas in 2085 than now, the temperature-related increment in urban water use is likely to be larger than it is now.

[19] An alternative scenario would assume that the region invests more heavily in insurance in the form of expanded baseload supply, and then experiences a reduced degree of shortfall. There is still an economic loss from climate change in this case, but the nature of the loss is different: less of the loss is in the form of shortage costs in dry years, and more is in the form of a higher cost of water supply in normal years due to the extra cost of securing baseload supply.

[20] Like many of the other assumptions made in this report, this is something that can be varied and tested via a sensitivity analysis. Such sensitivity analysis will be conducted in our future work.

TABLE 3. IMPACT OF CLIMATE CHANGE AND POPULATION GROWTH ON SOUTH COAST URBAN WATER SUPPLY

	BASE CASE: 2000 SERVICE POPULATION, NO CLIMATE CHANGE	
	AVERAGE ANNUAL WATER SUPPLY '000 AF	
(a)	Surface water from SWP and LAA	1,554
	Other sources	2,693
	Total	4,247
	CLIIMATE CHANGE, 2070-2099, 2000 SERVICE POPULATION	
	AVERAGE ANNUAL WATER SUPPLY ('000 AF)	
(b)	Surface water from SWP and LAA	1,256
	Other sources	2,693
	Total	3,949
	REDUCTION IN AVERAGE ANNUAL SUPPLY DUE TO	
	CLIMATE CHANGE ('000 AF)	
(c)	(a) - (b)	298
	SUPPLY INCREMENT NEEDED FOR 2070-99 POPULATION ('000AF)	
	Increase in average annual urban demand 2000 - 2085	2,600
	Additional "insurance"	130
(d)	Total	2,730
	NEEDED INCREMENT IN SUPPLY TO MEET POPULATION	
	GROWTH AND CLIMATE CHANGE ('000 AF)	
	(c) + (d)	3,028
	ADDITIONAL CLIMATE-SENSITIVE SURFACE WATER SUPPLY ('000 AF)	1,514
	ADDITIONAL NON-CLIMATE SENSITIVE SUPPLY ('000 AF)	1,514

Although the new supplies ensure that the region can meet its demands (with a 5% margin to spare) in an average year over the period 2070–2099, in any particular year there can be a surplus or a shortfall because of the variation in annual weather conditions. The monthly and annual variation are simulated via CalSim-II, which runs the 2070–2099 hydrology over a 73-year period representing the month-to-month and year-to-year variations that were experienced between 1922 and 1994.The results of this simulation are shown in Table 4 for the driest 26 of the 73 years (35%). The first column of the table shows the historical year which is represented as transformed by the specific hydrologic scenario being simulated. Two scenarios are being simulated here: the historical hydrology of 1961–1999, and the climate change hydrology of 2070–2099; in each case the 30 years of the scenario is "spread out" over the 73 years of the simulation. The simulations are applied just to the surface water supplies from the SWP and LAA, but not to the other supplies (from the Colorado Aqueduct and local surface water and groundwater) which are treated as invariant for the purpose of the simulation (see columns 3 and 7).

TABLE 4. IMPACT ON DROUGHT FREQUENCY AND SEVERITY												
	2000 SOURCES OF SUPPLY NO CLIMATE CHANGE ('000 AF)			SUPPLY AS % OF 4.2 MAF	**2000 SOURCES OF SUPPLY 2070-2099 CLIMATE (('000 AF)**			**SUPPLY REDUCTION ('000 AF)**	**NEW SUPPLIES ('000 AF)**		**TOTAL SUPPLY ('000 AF)**	SUPPLY AS % OF 6.8 MAF
"YEAR"	SWP & LAA	OTHER	TOTAL		SWP & LAA	OTHER	TOTAL		CLIMATE SENSITIVE	NON-CLIMATE SENSITIVE		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1924	941	2,693	3,635	86.5%	526	2,693	3,219	-415	634	1,514	5,368	78.9%
1925	965	2,693	3,658	87.1%	543	2,693	3,236	-421	655	1,514	5,405	79.5%
1926	1,505	2,693	4,198	100.0%	579	2,693	3,272	-926	698	1,514	5,484	80.6%
1929	979	2,693	3,672	87.4%	657	2,693	3,350	-322	792	1,514	5,656	83.2%
1930	1,327	2,693	4,020	95.7%	534	2,693	3,227	-792	644	1,514	5,385	79.2%
1931	892	2,693	3,586	85.4%	446	2,693	3,139	-447	537	1,514	5,190	76.3%
1932	963	2,693	3,656	87.0%	599	2,693	3,292	-364	722	1,514	5,529	81.3%
1933	896	2,693	3,590	85.5%	388	2,693	3,081	-508	468	1,514	5,063	74.5%
1934	908	2,693	3,601	85.7%	403	2,693	3,096	-505	486	1,514	5,096	74.9%
1935	1,587	2,693	4,281	101.9%	884	2,693	3,577	-703	1,065	1,514	6,156	90.5%
1937	1,712	2,693	4,405	104.9%	1,196	2,693	3,889	-516	1,442	1,514	6,845	100.7%
1947	1,683	2,693	4,376	104.2%	858	2,693	3,551	-824	1,035	1,514	6,100	89.7%
1948	1,617	2,693	4,310	102.6%	983	2,693	3,677	-633	1,186	1,514	6,376	93.8%
1949	1,425	2,693	4,118	98.1%	792	2,693	3,485	-633	955	1,514	5,954	87.6%
1950	1,694	2,693	4,387	104.5%	950	2,693	3,643	-744	1,145	1,514	6,303	92.7%
1960	1,202	2,693	3,895	92.7%	839	2,693	3,532	-363	1,012	1,514	6,058	89.1%
1961	1,427	2,693	4,120	98.1%	861	2,693	3,554	-566	1,038	1,514	6,106	89.8%
1964	1,861	2,693	4,555	108.4%	962	2,693	3,655	-900	1,159	1,514	6,328	93.1%
1976	1,728	2,693	4,421	105.3%	851	2,693	3,545	-876	1,026	1,514	6,085	89.5%
1977	766	2,693	3,459	82.4%	372	2,693	3,065	-394	449	1,514	5,028	73.9%
1987	1,659	2,693	4,352	103.6%	896	2,693	3,589	-763	1,080	1,514	6,183	90.9%
1988	864	2,693	3,558	84.7%	616	2,693	3,309	-249	742	1,514	5,565	81.8%
1989	1,384	2,693	4,077	97.1%	894	2,693	3,587	-490	1,078	1,514	6,179	90.9%
1990	980	2,693	3,673	87.4%	702	2,693	3,395	-278	846	1,514	5,754	84.6%
1991	661	2,693	3,354	79.9%	424	2,693	3,117	-237	511	1,514	5,142	75.6%
1992	747	2,693	3,440	81.9%	375	2,693	3,068	-373	452	1,514	5,033	74.0%
AVERAGE	1,245	2,693	3,938		697	2,693	3,390	-548	841	1,514	5,745	84.5%

Columns (2) through (4) in Table 4 represent the base 1961–1999 hydrology applied to the South Coast region with its 2000 level of population and urban demand. In this base case, 13 years out of the 73 years simulated had a supply shortfall of 5% or more; the average shortfall in those 13 years was 15% (i.e., on average in these 13 years, supply equaled 85% of the postulated 4.2 MAF urban demand). Column 6 shows how the SWP and LAA supplies change when one switches to the 2070–2099 hydrology; while the average delivery from the SWP and LAA supplies over all 73 years falls by an average of 298,000 acre-feet (Table 3), in the 26 driest years it falls by an average of 548,000 acre-feet—that is, the driest years become drier under the climate change scenario. Columns 10 and 11 add in the incremental 3.03 MAF of new supplies needed to offset the effects of climate change and population growth on average demand and supply in the region. Half of this new supply is assumed to be insensitive to climate variation (column 11), while the other half is assumed to vary with climate in the same way as the SWP and LAA supplies: each entry in column 10 consists of the 73-year average supply (1.514 MAF) multiplied by the ratio of the SWP and LAA supplies in that year to their 73-year average. Columns 12 and 13 show the resulting supply shortfall in relation to the postulated 6.8 MAF urban demand. With climate change and this supply scenario, these 25 years out of the 73 years simulated all have a supply shortfall of 5% or more—twice the number in the base case—and the average shortfall in these years amounts to 16.2%, compared to 15% in the base case. Droughts become more frequent and more severe in this situation; they also become more persistent, in that there are longer runs of back-to-back drought years than in the base case.

The economic costs of these reductions in urban water supply in the South Coast are shown in Table 5. As noted above, these consist of two components. One item is the cost of the 298,000 acre-feet that is lost from existing SWP and LAA supplies due to the climate change scenario. Valuing the replacement supply at about $1,000/AF makes this an recurring annual cost of $300 million.[21]

[21] A & N Technical Services (2004) estimate that the avoided cost of conserving an acre-foot of water in the South Coast region is $639 (in 2003 $) in 2000 and, because of increasing scarcity, this rises in constant dollars to $806 in 2040. The same rate of increase extrapolated to 2085 yields over $1000/af in 2003 $.

TABLE 5. ECONOMIC COST OF REDUCTION IN URBAN WATER SUPPLY

(A) COST OF REPLACEMENT FOR REDUCTION IN EXISTING AVERAGE SUPPLY

$300 MILLION

(B) COST OF SHORTAGES TO RESIDENTIAL WATER USERS IN SHORTAGE YEARS

	HISTORIC CONDITIONS			**CLIMATE CHANGE CONDITIONS**			
"YEAR"	OVERALL SYSTEM SHORTAGE	% SHORTAGE FOR RESIDENTIAL USERS	LOSS OF CONSUMER'S SURPLUS $ million	OVERALL SYSTEM SHORTAGE	% SHORTAGE FOR RESIDENTIAL USERS	LOSS OF CONSUMER'S SURPLUS $ million	NET LOSS OF CONSUMER'S SURPLUS $ million
1924	13.5%	17.6%	$3,289	21.1%	26.4%	$6,537	$3,248
1925	12.9%	16.7%	$3,042	20.5%	25.6%	$6,196	$3,154
1926	No Shortage	0.0%	$0	19.4%	26.3%	$6,491	$6,491
1929	12.6%	16.2%	$2,895	16.8%	22.5%	$4,990	$2,095
1930	No Shortage	0.0%	$0	20.8%	26.0%	$6,376	$6,376
1931	14.6%	19.3%	$3,840	23.7%	30.3%	$8,296	$4,456
1932	13.0%	16.8%	$3,060	18.7%	25.3%	$6,079	$3,019
1933	14.5%	19.1%	$3,794	25.5%	33.0%	$9,674	$5,880
1934	14.3%	18.7%	$3,660	25.1%	32.3%	$9,312	$5,652
1935	No Shortage	0.0%	$0	9.5%	14.0%	$2,295	$2,295
1947	No Shortage	0.0%	$0	10.3%	12.8%	$1,997	$1,997
1948	No Shortage	0.0%	$0	6.2%	9.2%	$1,210	$1,210
1949	No Shortage	0.0%	$0	12.4%	16.0%	$2,839	$2,839
1950	No Shortage	0.0%	$0	7.3%	10.8%	$1,538	$1,538
1960	7.3%	10.8%	$1,521	10.9%	13.8%	$2,225	$704
1961	No Shortage	0.0%	$0	10.2%	12.7%	$1,965	$1,965
1964	No Shortage	0.0%	$0	6.9%	10.3%	$1,422	$1,422
1976	No Shortage	0.0%	$0	10.5%	13.2%	$2,078	$2,078
1977	17.6%	23.7%	$5,450	26.1%	33.8%	$10,081	$4,631
1987	No Shortage	0.0%	$0	9.1%	13.5%	$2,146	$2,146
1988	15.3%	20.3%	$4,172	18.2%	24.5%	$5,758	$1,587
1989	No Shortage	0.0%	$0	9.1%	13.6%	$2,171	$2,171
1990	12.6%	16.2%	$2,887	15.4%	20.4%	$4,215	$1,327
1991	20.1%	25.0%	$5,962	24.4%	31.3%	$8,803	$2,842
1992	18.1%	24.4%	$5,711	26.0%	33.7%	$10,015	$4,304
AVERAGE	14.3%	18.8%	$3,791	16.2%	21.3%	$4,988	$3,017

only includes shortage years

The second item is the economic cost to urban users when shortages occur. This is estimated as follows. We that there is no economic loss until the shortage exceeds 5% of the normal demand: urban water agencies handle smaller shortages by drawing on reserve storage and/or by calling for voluntary conservation, so they generate no economic loss.[22] However, when the shortage exceeds 5%, we assume that the water agency imposes mandatory rationing. We also assume that the water agency preferentially favors industrial and commercial users in the following manner. When shortage is between 5 and 10%, the water utility only rations residential users;[23] when the shortage is between 10 and 20%, the agency rations industrial and commercial users by only 5%, placing the remainder of the rationing burden on residential users;[24] and when the shortage exceeds 20%, the agency rations industrial and commercial users by 10%, placing the remainder of the rationing burden on residential users.[25] In the lower panel of Table 5, this rule is applied to the shortages described in column (13) of Table 4.

At this time we only quantify the economic loss to residential users who are rationed. In economic terms, the correct measure of their loss is their loss of consumer's surplus, which can be calculated as the change in the area under their demand curve for water corresponding to the rationing reduction.[26] Moreover, because this is an outage situation in which consumers are being rationed at relatively short notice, the relevant demand curve from which to compute the loss of consumer's surplus is their short-run demand function. This analysis assumes a linear demand function and a short-run price elasticity of -0.05. The resulting estimate of losses of consumer's surplus are shown in the last column of the lower panel of Table 5.[27] The loss varies with the degree of the shortage, and averages about $5 billion in a shortage year. An identical calculation applied to these same years in the base case indicates an average shortage loss of $1.7 billion per year. As a result of climate change, droughts now become twice as frequent and almost twice as costly. The net impact of climate change is over $3.2 billion per drought year. There would be some additional economic loss stemming from the reduction in production associated with the rationing of industrial and commercial users in years when the overall system shortage exceeds 10%, but this is not analyzed in detail here.

[22] Recall that, in dry years (which is when shortages typically occur), actual urban demand is likely to be at least 8.33% higher than the normal level. When this is factored in, the proposed 5% threshold for a shortage corresponds to something more like a threshold of 13% or more.

[23] This happens six times in the sequence of 73 years.

[24] This happens about 14% of the time (10 times in 73 years).

[25] This happens about 12% of the time (9 out of 73 years).

[26] A similar approach is used in DWR's Least-Cost Planning Simulation Model.; see DWR (2005a).

[27] The analysis assumes that the portion of retail cost corresponding to fixed costs (as opposed to variable costs) amounts to about $1000/AF in 2085.

To summarize, the loss to urban water users from the climate change scenario in 2085 consists of: (1) about $300 million annually to replace the loss in SWP and LAA supplies; (2) in about 35% of the years there would be rationing which imposed a cost to residential users averaging $5 billion in these years; and (3) in most of the shortage years there would also be 5% or 10% rationing for industrial and commercial water users which would generate some loss of economic production that has not yet been quantified. Given the size of the Southern California economy, the economic loss caused by rationing of water to industrial and commercial water users could be significant. A study by Spectrum Economics (1991) focused on the economic losses associated with a 30% reduction in water to industrial users in Southern California. Adjusted for inflation, but scaled back from a 30% to a 10% reduction, those results suggest that the economic costs of the disruption in supply to industrial users could well be on the order of $1 billion or more per year

5.0 Floods

The potential for flooding was noted in Section 2. Over the past two decades there have been four serious floods in the Central Valley. Today, more people are living in these floodplains than before. Therefore with the greater risk of flooding due to climate change and the larger population at risk, the chance of a significant loss of property from floods, and perhaps a loss of life, is greater than ever before. It seems likely that property damage from future flood events could well exceed one billion dollars.

TABLE 6. CENTRAL VALLEY HISTORICAL FLOOD DAMAGE (2005 $ million)

Year	Sacramento R Basin	San Joaquin R Basin	Total
1983	190	677	867
1986	322	28	350
1995	417	264	681
1997	395	292	687

Source: USACE (2002)

6.0 Concluding Observations

This report has provided a partial analysis of the economic costs caused by the reduction in surface water supply in California due to the GFDLA2 scenario. We have examined the economic impact on agricultural water users in the Central Valley and on urban users in the South Coast. Although the specific details of their water supply differ, it is likely that agricultural users in California *outside* the Central Valley and urban users *outside* the South Coast will suffer economic losses because of this climate change scenario. However, we are not yet in a position to estimate those losses.

Since the population outside the South Coast is projected to be at least as large as the population within the South Coast by 2085, it is possible that the economic impact on urban water users elsewhere in the state—especially the Bay Area and perhaps the

Central Valley—may be roughly equal in total magnitude to that of urban users in the South Coast.[28]

As noted earlier, the foregoing is only one scenario of what climate change might bring to water users in California. It is not the only possible scenario, and others will be considered in future work.

Two qualifications should be emphasized. First, the more storage developed by water agencies in the South Coast, whether above ground or below ground in the form of conjunctive use, the greater the chance of reducing economic losses due to shortages in dry years. This does not mean that there would not be any economic loss from climate change, however. Instead, the economic loss would take the form of the extra cost of increased storage needed to offset the supply uncertainty created by climate change. This has not been analyzed here. The additional storage could be costly, not just because of the construction cost but also because, with reduced surface water available statewide due to climate change, the storage could be less effective in terms of the effective amount of water it could deliver, leading to a higher cost per acre-foot delivered.[29] The other issue not addressed here is the increase in water transfers from agricultural to urban users. For example, if all of the water currently used by agriculture in Imperial Valley were transferred to urban users in the South Coast region, this would roughly make up the entire increment in supply needed to meet urban growth in the region between now and 2085. Whether or not that is a plausible scenario without climate change is not known. Also unknown is the potential effect of climate change on the total supply of water to California from the Colorado River. Even with more extensive water transfers from agricultural to urban users, it seems likely that climate change could create some shortages and impose some costs.

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[28] By 2085, the South Coast is projected to contain only about 46% of the total statewide population,

[29] By way of illustration, the local water agencies in the South Coast currently operate 24 reservoirs with a storage capacity of 745,000 acre-feet. The historic average yield of these local surface supplies, which come from reservoir releases and stream diversions, is about 130,000 acre-feet/year. Thus, the ratio of storage capacity to average annual delivery is significantly greater than 1:1.

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